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Review of Freeway Corridor Traffic Models

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Abstract:	The following models were reviewed for potential application to freeway-dominated corridors in Ontario: MACK, FREFLO, FRECON, INTRAS, TRAFFICQ, FREQ, CORQ-CORCON, SCOT, TRAFLO, DYNEV, CONTRAM, SATURN, and MICRO-ASSIGNMENT. Based on the literature review and a preliminary evaluation in view of some basic requirements, a short list of models was developed for detailed evaluation, consisting of FREQ, CORQ-CORCON, TRAFLO, DYNEV, CONTRAM, and SATURN. This detailed examination indicated that while none of the current models fully satisfy all major criteria, some models can be upgraded while others cannot. Consequently, CONTRAM and CORQ were recommended for further consideration, as they were most suitable for incorporating the required enhancements. Finally, specific improvements were outlined for purposes of both immediate application and long term development.
Key words:	computer-based traffic model, freeway traffic corridors, travel time, queueing, traffic simulation
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1/ INTRODUCTION

The Ontario Ministry of Transportation and Communications (MTC) has access to a number of models for the analysis and/or optimization of traffic signal systems, freeways, and corridors consisting of both freeways and signalized arterials. These models were developed for a variety of purposes and therefore have varying characteristics, advantages, and disadvantages.

MTC currently has a need for models to evaluate traffic management schemes for a number of freeway-dominated networks. Specifically, models are required for application to the Q.E.W., Burlington Skyway, Highway 401, and Ottawa Queensway corridors. It is anticipated that the applications will occur in this order.

The purpose of this study was to evaluate a number of existing models to ascertain what is currently available and what is required to support these applications.

The first step in the study was to develop a set of criteria for the evaluation and selection process. This was done in conjunction with MTC traffic systems research and traffic management and engineering personnel. The second step was a preliminary evaluation of the available models in terms of these criteria and the development of a short list of models which would form the basis for further study. The third step involved a detailed analysis of this short list of models, out of which the most appropriate model(s) would be selected for application and/or further development. These steps are reported in Chapters 2, 3, and 4 respectively, followed by a summary of the conclusions and recommendations in Chapter 5.

2/ MODEL EVALUATION AND SELECTION CRITERIA

This chapter establishes, defines and ranks the criteria used for evaluating the various candidate models.

2.1/ Introduction

A freeway corridor model may contain a wide variety of features, some of which are optional, others essential. The best quality model is not the one with the most features, however, but the one based in the best theory. The features of a model are formulated and incorporated into it based on the application that the theory addresses. Thus, depending on the application, different model features are included and/or emphasized.

This section sets out to establish which features are considered important, their importance relative to each other and the measures which can be used to measure the quality of their implementation in terms of:

- Quality of model in terms of traffic engineering theory
- Quality of program code
- User friendliness and documentation
- Field validation and verification
- Availability, implementation, cost and support

GENERAL CONSIDERATIONS:

- Representation of Reality
- Accuracy and Precision
- Efficiency
- Versatility and Generality
- Suitability for Improvements and Upgrading

RATING SYSTEM:

Absolutely Necessary	***
Desirable Now and Necessary in Future	**
Desirable	*
Not Important	-

2.2/ Quality of Model in Terms of Traffic Engineering Theory

The model properties and characteristics covered under this heading address the traffic engineering quality of the modelling approach. Primarily, the emphasis is placed on determining whether the given model can represent the various relevant aspects of traffic flow and assignment, and to establish the quality of this representation. It should be noted that some of these factors are interrelated and therefore may apply to several categories.

2.3/ Quality of Program Code

The quality of the program relates to the features of the model in terms of how well the model's theory has been translated into computer code. The factors relating to user friendliness describe the model's ease and flexibility of use, and its overall appearance to the user.

2.4/ Model Validation and Verification

The extent of validation and verification of the model does not directly contribute to the model's quality, but rather enhances the user's confidence in the model. These factors have been further subdivided, since the overall quality of the validation and verification depends upon the person who performed it, and what types of data were used (real data being preferred to artificial data, and external use to internal use).

Table 2.1/ Traffic Engineering Theory Evaluation Criteria

CRITERIA	IMPORTANCE RATING
1. FREEWAYS:	
Queuing	***
Merging and Weaving Sections	***
Ramp Metering	***
Balancing of Collector/Express Lanes	***
Car-following and Lane-changing Behavior	-
Analysis of Shock-waves	-
Priority Entry and Lane Provision	**
Over-Saturation and Queue Spill-back	***
2. TRAFFIC SIGNALS:	
Cycle Length, Phasing and Green Split	***
Co-ordination and Progression	**
Platoon Dispersion	-
Critical Intersection Control	-
Over-Saturation and Queue Spill-back	***
Length of Time Slice Effects	*
Dynamic Adaptation of Capacity	**
3. ASSIGNMENT:	
Queuing	***
Dynamic Re-Assignment	***
Bi-Directional Corridors	**
Vehicle and Facility Types	*
4. OTHER FACTORS:	
Adaptive Learning (day-to-day)	*
Off-line (study tool)	***
On-line (traffic responsive)	**
Suitable for Optimization	***

Table 2.2/ Program Code Evaluation Criteria

CRITERIA	IMPORTANCE RATING
1. PROGRAM SOURCE CODE:	
Clarity	**
Comments and Internal Documentation	**
Modular Structure	**
Suitability for Modification if Required	***
2. PROGRAM EFFICIENCY AND LIMITATIONS:	
Maximum Size of Network (500 links, 250 nodes)	**
Execution Time (10 min mainframe, 16 h micro)	**
Efficient to Run for Optimization of Network	**
Portability Between Mainframes	***
Transferability to Micros (PC)	**
3. INPUT DATA:	
General User Friendliness:	
Automated Input	*
Error Checking and Messages	*
Editing of Input Data	*
Synthetic Data	*
Accessibility to Optimization Module	**
4. OUTPUTS AND RESULTS:	
Flows, Queues, Travel Times, Speed by Link	***
Graphical Presentation	**
Fuel Consumption	*
Emissions	*
Noise Pollution	*
Summaries by Classification	**
5. EXTERNAL DOCUMENTATION:	
Description of Model's Theory	**
Software Installation and Maintenance	**
Description of Model Limitations	**
Interpretation of Results	**

Table 2.3/ Field Validation and Verification

Data	Using Artificial Data Using Actual Data (preferred)
User	By Model Author By Other Users (preferred)

Table 2.4/ Model Availability, Implementation, Cost and Support

ITEM	RATING
1. Model Availability	
Cost	***
Source Code	***
Additional Support and Followup	***
2. Implementation	
Common Mainframe	***
Mini Computer	**
Micro Computer	**

Table 2.5/ Summary of Most Important Factors

Freeways	- Oversaturation and Queue Spill-back - Merging and Weaving - Ramp Metering - Collector/Express Lane Balancing - Queueing
Traffic Signals	- Automatic Conversion of tt = f(C,G,O) - Oversaturation and Queue Spill-Back
Assignment	- Dynamic Re-assignment - Queueing
Other Factors	- Off-Line Study Tool - Suitable for Optimization
Source Code	- Availability - Suitability for Modification
User Friendliness	
Outputs and Results	- Flows, Queues, Travel Times by Link
Model Availability	- Cost - Source Code - Additional Support
Implementation	- Any Mainframe or Mini Computer

2.5/ Model Availability, Implementation, Cost and Support

The first group of factors attempts to identify how easy it is to obtain and possibly modify the given model, while the second group examines the flexibility of the model in terms of the hardware upon which it can be implemented.

Source code availability is important because it permits custom modifications to be made, while the additional support makes it easier to use the available code and documentation.

While the major users of the model will likely implement the model on a mainframe computer, use of the model on a mini or micro computer would be desirable. It makes the model available to a wider clientele, and even allows the major user to prepare and/or alter the model for its ultimate application by simple accessible means. This tends to expedite the overall process.

2.6/ Summary of Most Important Model Factors

Based on the above detailed rating of the various model factors, the following table provides a summary of the most important factors. Factors were defined as being important if, in their detailed evaluation, they were rated "***" (absolutely necessary).

3/ PRELIMINARY EVALUATION OF CANDIDATE MODELS

A wide variety of different models have been developed to model various aspects of freeways and freeway corridors. The following review will present a preliminary evaluation of the most important of these, such that a short list of candidate models can be recommended.

3.1/ Introduction

From among the wide range of factors described in the previous chapter, those factors directly related to the quality of the model's theory are used in this section to derive the short list of models to be evaluated in more detail in the next chapter.

In the selection of candidate models, the soundness of a model's theory is of prime importance, as it characterizes the model. Furthermore, it is much easier to make other enhancements to a model with sound theory, than it is to upgrade the theory of a model which has many features but a fundamental flaw in its structure. The preliminary screening, therefore, identifies those models which might be able to predict the important traffic flow, queue and assignment-based phenomena required for evaluating traffic management schemes in a corridor.

Specifically, the following section will present the initial review of each model, a tabular summary of the various preliminary model properties and characteristics, and the short-list of those models which are selected for further evaluation.

3.2/ Review of Candidate Models

A number of researchers have attempted to enumerate the various types and versions of models that have been developed for the purpose of evaluating freeways and freeway corridors. Examples of these have been published by Hsu and Munjal (1974), Ross and Gibson (1977) and May (1981). The present review has more specific objectives, and therefore does not intend to be exhaustive in terms of each historical version, or each incremental effort.

In contrast, this review focusses primarily on the final or most recent version of each model, and considers only those models which are currently ready for implementation. It compares the relative merits of each of these candidate models and produces a short list of those models which are to be evaluated in more detail.

Specifically, the following models or model types are considered:

- MACK-FREFLO-FRECON-series
- INTRAS-type
- TRAFFICQ
- FREQ-series
- CORQ-CORCON-series
- SCOT-family
- TRAFLO-type
- DYNEV
- CONTRAM-SATURN-types
- MICRO-ASSIGNMENT-type

Each model type, series or family is discussed in terms of its general characteristics and performance. This is followed by a more critical examination of the model's strengths and weaknesses. In conclusion, an estimate of the anticipated relevance of the given model to the needs and objectives of MTC is presented.

3.2.1/ MACK-FREFLO-FRECON series

MACKII model (Payne, H.J. et al., 1977), and the MACK model (Payne, H.J., 1971) are deterministic, macroscopic models that basically consist of a set of conservation equations and corresponding set of speed-density equations. A later modification by Koble, M. et al. (1980) was developed at Orincon and has unofficially been labelled as MACKIII. MACK models incidents but there are presently no provisions for environmental impact measures or parallel routes. The program is modular and has primarily been used by its authors (Babcock et al, 1982). The model was evaluated by Derzko et al (1983), who found the model to contain instabilities.

The FREFLO model is a further development of the MACKII model. Guidelines for its use, a description of the actual model, and a critical review of the model are presented in Payne (1978, 1979a, 1979b), respectively. The model contains three general control strategies, can model incidents, and has options for fuel and emission measurements. It cannot model parallel routes. FREFLO is also a modular program and has been used by second parties (Babcock et al, 1982). Derzko et al (1983) also evaluated this model and found that, by virtue of an identical underlying differential equation, FREFLO exhibited the same instabilities as were found in MACK. FREFLO is said to be a dynamic formulation as its outputs depend upon some previous inputs and the present inputs. This dependence is often described using differential equations. In general, FREFLO is derived from car following theory (Payne, 1971), and its overall characteristics may also be derived from statistical considerations (Phillips, 1979).

FRECON (Babcock et al, 1981) and its update FRECONII (Campbell et al, 1984) are dynamic macroscopic freeway simulation models which have been developed from Payne's FREFLO model. The original version simulates freeway performance and generates point detector information for calibration and validation. The model can interact with control programs in order to evaluate pretimed, local traffic response, and segment-wide control strategies. Incident simulation is also possible. Traffic data must be included in the form of on-ramp and off-ramp volumes, and mainline volumes. Optional inputs pertain to detector location and incident description. In addition to the traditional output, the model also generates contour maps of traffic performance measures and time profiles (Skarbardonis, 1984).

In addition to the features of FRECON, FRECONII can simulate alternative routes (surface streets), and hence the model simulates a freeway corridor. It can simulate a freeway with mixed modes of ramp metering, and the driver's spatial diversion due to ramp metering. Additional outputs include surface street performance, corridor performance, and effects due to occupancy and diversion effects (Skarbardonis, 1984).

3.2.2/ INTRAS-type

INTRAS (INTegrated TRaffic Simulation) (Wicks, 1977, Wicks et al, 1980) uses network theory to interrelate freeway and arterial traffic. INTRAS is a stochastic, microscopic model especially developed for studying freeway incidents. It is a vehicle-specific time-stepping simulation designed to realistically represent traffic and traffic control in a freeway and surrounding surface street environment (May, 1981).

The program is quite large and complex so as to model all vehicle motions in the corridor. A few control strategies are incorporated into the model but it may be difficult to allow for access of new control strategies due to the model's structure. Traffic detectors and fuel and emission data are simulated directly from the microscopic flow (Babcock et al, 1982).

Users of INTRAS have reported problems with some aspects of traffic behaviour (Bullen, 1982). They relate mainly to the vehicles that merge from acceleration lanes, vehicle behavior at exit ramps, and the method of assigning destinations. Some of these relate to the complications of communication between vehicles across link boundaries.

FOMIS (Bullen, 1982) provides a revised model structure that is intended to streamline the simulation process by restricting it to the freeway only, eliminating the link structure, and reducing vehicle processing to a single scan. Full derivation of car-following and lane-changing algorithms is given in Bullen (1976) and Bullen and Cohen (1980). It is primarily intended as a supplemental tool to current macro-analysis methods.

3.2.3/ TRAFFICQ

TRAFFICQ is a simulation model of pedestrian delay, vehicle queueing and platooning behaviour, which takes into account dynamic and stochastic variations, varying roadwidths, and movements temporarily blocked by vehicles waiting to cross an on-coming stream of traffic. Complex contr-ol techniques such as linked signals, or vehicle- or

pedestrian-actuated signals may be modelled, as may priority junctions. Each vehicle and pedestrian is modelled as an individual entity and the output gives distributions of queue lengths, travel times and pedestrian delay (Logie, 1979).

TRAFFICQ is both dynamic and stochastic. It models, for example, both varying flow levels and random variations in discharge rates of vehicles from stop lines. The technique is aimed at relatively small scale systems, even merely complex junctions.

The program is written in ICL's CSL simulation language, which moves vehicles in discrete step time increments (four to six seconds). The model is divided into a series of "activities" which are scanned sequentially and the instructions within them are only performed if a particular condition is met. Such use of simulation permits tracing of dynamic conditions and evaluation of consequences of short lived effects. In addition, it permits the evaluation of stochastic factors through use of a frequency distribution for the derivation of some traffic parameters.

Routes taken by vehicles are pre-specified by the user. This makes multi-routing possible, but also implies that no internal assignment technique is present. Each vehicle and pedestrian is considered as an individual entity and temporary blockages and queue tail backs are modelled in detail.

3.2.4/ FREQ-series

Since 1968, a series of freeway models belonging to the FREQ family have been developed primarily at the University of California (May, 1984). Some of these models are progressive improvements on previous versions, while others are extensions dealing with more specialized situations or applications.

FREQ-models are macroscopic freeway models, which are generally intended to evaluate in detail a directional freeway and its ramps, based on ramp O-D information. Some diversion to parallel alternatives is considered for vehicles queued on on-ramps, but this treatment is not very detailed. Specialized versions of the general model are available for the

evaluation of reserved lanes on freeways for carpools and/or buses, or the evaluation of priority entry and normal entry control.

The major input to these models is a set of O-D tables for each interval or time-slice (typically about 15 minutes). These tables would correspond to single-occupant cars, two-occupant cars, three-occupant cars, etc., with the sixth or final table referring to buses. Alternatively, these other tables might be input as percentages of the original total O-D. The model can calculate the effect of weaving on capacity and speed-flow relationships can be selected or specified by the user. Ramp characteristics must be input. The model adjusts supply and demand, and predicts a time stream of impacts which includes both spatial and modal traveller responses (OECD, 1981). The output consists of freeway performance tables, containing travel time, speed, ramp delays and queues, fuel consumption and emission.

FREQ6PL, by Cilliers, Cooper and May (1978, 1979), is used primarily for the evaluation of freeway lane(s) reserved for car pools and/or buses. It requires the user to specify the priority lane design configuration, the number of people that constitute a legal carpool, and the time duration of priority operations (OECD, 1981).

FREQ7PE (Roden et al, 1980) is developed primarily for the evaluation of priority entry and normal entry control on a directional freeway. The model can also be used for evaluating design improvements with or without freeway entry control. As inputs it also requires the control parameters and ramp metering constraints. The program simulates the system, implements a control strategy through linear programming optimization, and predicts traffic performance and traveller demand responses. Also produced are metering plans, contour maps, and short and long term impacts of priority lane operation (Skabardonis, 1984).

The FREQ6PL model has been applied to the Santa Monica Freeway in Los Angeles and, through sensitivity analysis, policy guidelines have been proposed. The FREQ6PE model has been applied to the Eastshore Freeway in the San Francisco Bay Area and here also some initial policy guidelines have been proposed (OECD, 1981).

3.2.5/ CORQ-CORCON-series

CORQ (Yagar, 1970 and 1975) is a dynamic assignment technique for assigning time-varying demands to a time-dependent traffic network. The technique was designed to model the impact of queueing and ramp metering on traffic assignment within a freeway corridor. CORCON (Allen and Easa, 1977) is a modification of the CORQ program which has incorporated turn prohibitions, a queue diversion formula, and a graphical output of the turning movements at major intersections or interchanges.

CORQ (CORridor Queueing) considers O-D movements for a freeway/arterial corridor and assigns these in accordance to minimum path and equilibrium considerations for each time slice. Traffic flows unable to reach their destination within the given time period due to capacity constraints are queued and re-assigned to the network during the subsequent time-slice. Vehicles are assigned in variable sized increments, depending upon the capacity of the links of the network, and solutions for each time-slice are iterated upon until equilibrium is reached.

Traffic flows are approximated as fluids, and travel times are calculated as simple step functions for both free-flowing and congested (queueing) conditions. The model considers primarily a directional freeway, its ramps, major cross-streets and any competing parallel surface streets. Turning movements can be accounted for, but no explicit modelling of traffic lights or any progression effects take place. These effects must be input as link characteristics.

CORCON (freeway CORridor assignment and CONtrol model) is an extension of the CORQ program code, with patches, rather than generic changes to CORQ. Consequently, only the additions to and differences from the original program are discussed.

CORCON uses a link-node representation for the network which uses fewer links and nodes, but which avoids illogical paths through the use of turn-prohibitions. It also includes a modified minimum path algorithm which can accommodate the complications introduced by this simplified link-node representation and the turn-prohibitions.

Also included is a queueing diversion formula which diverts a fraction of those drivers using a congested minimum path, to an alternative path which does not contain any saturated links (but has a longer overall trip time). Further additions include a technique for overlaying old and new minimum paths for queued links, and a method for calculating turning movements without explicit use of turning links. Easa (1982) elaborated on some further extensions that are included in CORCON6F. These include some improvements in the efficiency of the program, the addition of fuel consumption calculations, streamlining of I/O formats, and the generation of a series of summary statistics classified by type of measure, type of link, etc.

3.2.6/ SCOT-family

SCOT (Simulation of COrridor Traffic) (Lieberman, 1972 and Lieberman and Wicks, 1972) was developed at the General Applied Science Laboratories. It is the synthesis of two previous models: UTCS-1 (Bruggeman, Lieberman and Worrall, 1971) and the DAFT model by Lieberman (1970), with later modifications reported in FHWA (1975). SCOT tailors the degree of detail to the type of network link being processed, and interface problems associated with this dichotomous logic are said to be resolved as part of the design.

UTCS-1 is a microscopic simulation of urban traffic, wherein each vehicle is treated as an individual entity as it traverses its path through a network of urban streets. Routing is performed based on specification of turning movements.

DAFT (Dynamic Analysis of Freeway Traffic) is a macroscopic simulation of traffic along a network of freeways, ramps and arterials. Vehicles are grouped into platoons and lose their individual identities. The platoons are moved along the freeway according to a single prespecified speed-density relation that applies to all freeway links. Along the non-freeway links, they travel at the specified free-flow speed for each link and are delayed at the downstream end for a time related to the ratio of green time to signal cycle time, and the volume of traffic on the link.

For each entry link at the periphery of the network considered, traffic volumes are specified according to their destination node. The model distributes the resulting platoons of vehicles over the network so as to satisfy these specified O-D patterns and to follow minimum-cost paths. These minimum-cost paths are calculated frequently by the model, based on current conditions. Whenever a platoon reaches a network node, its turning movement is dictated by its minimum-cost path as it exists at that instant of time. Hence the model produces a dynamic assignment of traffic as a by-product of the simulation.

It is a mesoscopic model which applies car-following theory to platoons of vehicles. It models parallel routes microscopically, but there is no availability for environmental analysis. Although ramp metering is allowed, the inclusion of new control strategies is restricted by the difficulty of program modification due to the model's structure (Babcock et al, 1982).

The SCOT model was calibrated and tested in the Dallas North Central Expressway study by the Transportation Systems Center (McCabe, Ricci and Coucannon, 1975). Tests showed no significant differences between field and simulation results for basic parameters of traffic speed, flow and saturation, but a demonstration of the O-D traffic assignment capability of the model indicated that the minimum time-path criteria used have not been conclusively shown to be the correct criteria for traffic assignment (May, 1981).

3.2.7/ TRAFLO-type

TRAFLO (Lieberman and Andrews, 1980) is a system of five models that interface with each other:

- 4 models which simulate traffic operations
- 1 model which carries out traffic assignment

Essentially, the traffic assignment model calculates the spatial distribution of traffic within the network, while the impact of this spatial distribution is evaluated to various degrees of details using one or more of the four simulation models.

Traffic assignment is performed using the TRAFFIC model which assigns a specified trip table to the specified network which is compatible with the four simulation models. The TRAFFIC model uses the U.S. Bureau of Public Roads formulation to relate link travel time to volume (Nguyen, 1974 and Nguyen and James, 1975) and then calculates link-specific volumes that minimize an objective function representing Wardrop's first principle.

Each of the four simulation models describes traffic operations in a sub-network with a different degree of detail. The user may partition the analysis network into sub-networks if more that one simulation model is to be used concurrently. The user must also specify "interface nodes" at the juncture of subnetworks. The following is a brief description of each of the four component submodels:

Urban Level I Model (NETFLO I) is the most detailed model, as each vehicle is treated as a separate identifiable entity and three vehicle type distinctions are permitted (automobiles, trucks, and buses). The simulation moves vehicles based on activation times and leaves them dormant between activation times. Details of the model are provided by Davilla and Lieberman (1980).

Urban Level II Model (NETFLO II) is supposed to be an extension and refinement of TRANSYT as the traffic stream is represented in the form of movement-specific statistical histograms. The simulation uses five histograms: Entry, In, Service, Queue, Out. Details of this model can be found in Yedlin and Lieberman (1980).

Urban Level III Model (NETFLO III) models the network's major arterials: collectors, distributors, circulators, and connectors. These routes either connect the high density area to traffic generators or to other high density areas. The models are based on Webster and Cobbe (1966).

The Freeway Model (FREFLO) is said to be an extension and refinement of the MACK model developed by Payne, Thompson and Isaken (1973) at the University of Southern California. In this case traffic is represented through fluid flow analogy by aggregate measures such as flow rate, density, and space mean speed.

3.2.8/ DYNEV

DYNEV was developed to estimate evacuation travel times in Emergency Planning Zones (EPZ) as part of the larger software system developed for the Emergency Exercise Simulation Facility (KLD, 1984). Its main components are PREDYN (a routine for interactive input or input modification) and I-DYNEV (a software system consisting of three functional components: a traffic assignment model, a traffic simulation model, and a traffic capacity submodel).

The model is driven by PREDYN, and at the end of the input PREDYN calls I-DYNEV. Each execution of I-DYNEV must be hand started, but modified original data can be employed. The use of DYNEV is an iterative procedure containing the following steps:

1. Input roadway network configuration, evacuation trip table, and existing network.

2. Execute assignment (compute routing and turning movements)

3. Possibly modify controls and/or trip table if improvements appear possible (repeat steps 2 and 3).

4. Execute I-DYNEV Traffic Simulation Model based on traffic volumes and turning movements generated from assignment.

5. Possibly modify controls and/or trip table if improvements appear possible (repeat steps 2 to 5).

6a. If step 5 affects routing, modify input stream and repeat process.

6b. If output of simulation is compatible with original assignment, procedure is complete.

The assignment model identifies the best travel times for people to move from specified origins within the EPZ to destinations just outside the EPZ boundary. It uses a modified TRAFFIC algorithm, considering routing

based on individual path minimization. Travel times are calculated on a B.P.R. travel time versus volume relationship.

The traffic simulation model takes as inputs link volumes and turning movements from the assignment model, and is intended to replicate the dynamic (time-varying) movements of the traffic stream on all roadway sections. The model, an adaptation of TRAFLO Level II, describes the traffic stream in terms of a set of link-specific statistical flow histograms with some extensions in scope to accommodate all types of facilities.

Both the assignment and the simulation model interact with the traffic capacity submodel, which computes service rates by turn movement.

3.2.9/ CONTRAM-SATURN-type

In response to the need for performing trip assignment and re-assignment in a signalized network, several different models were developed in Britain. The most popular of these are CONTRAM and SATURN, which are discussed below.

CONTRAM

CONTRAM (CONtinuous TRaffic Assignment Model) is a traffic assignment/evaluation package which models traffic flows as vehicle packets (Leonard et al, 1978 and Leonard and Gower, 1982). These packets are assigned to a traffic network consisting primarily of signalized and give-way intersections.

Demands are expressed as O-D rates per time interval, which are assigned at a uniform rate as vehicle packets. Each such packet is indivisible and travels along its own individual minimum path to its destination. Along this path, flows and travel times are updated for use by subsequent departures.

Travel times are calculated based on oversaturation, red indication and random delay. These consider delays due to extended queueing, traffic signals, and the random arrival of vehicles, respectively. Delay

functions for traffic signals can be updated to reflect optimization of signal split and/or overall cycle time. Coordination between adjacent signals is not considered. Equilibrium is achieved through iterations in which each vehicle packet in turn is removed from the network. Subsequently, a new minimum path is calculated and the packet is placed on this path. Such analysis considers each driver as truly a marginal user.

SATURN

SATURN (Hall, Van Vliet and Willumsen, 1980), is a traffic assignment model based on a two phase process, consisting of a detailed simulation of delays at intersections, and an assignment based on these calculated delays.

Intersection delays are determined using cyclical profiles, as in TRANSYT. Based on estimates of free-flow delay, these cyclic profiles, and delays at capacity, an aggregate power curve is fitted through these three points. This curve is then used in the assignment phase to calculate the paths taken for each origin-destination flow.

Traffic flows are estimated using a weighted combination of all-or-nothing assignments. These new estimates of link flow are re-evaluated with the cyclic profile approach until equilibrium is reached. This iterative approach accounts for the magnitude and platoon structure of traffic flows on the given link, as well as on any opposing direction flow which might interfere.

3.2.10/ MICRO-ASSIGNMENT-type

MICRO-ASSIGNMENT is a microscopic adaptation of traditional transport planning assignment techniques. Traffic is assigned in a conventional fashion, but the network is coded in considerably more detail such that individual movements and/or lanes can be considered (Brown and Scott, 1970 and Chenu, 1977).

Network coded using an "off-set" system of network representation, in which the nodes are located along the approaches to an intersection, and

each permissible traffic movement at the intersection is represented by a separate link. Two types of delays are considered: zero-volume delay and congestion delay. The former considers delays in absence of other vehicles (acceleration, deceleration for turns, and stop and yield signs). The latter considers delays due to traffic interference of other vehicles (queueing at signals or when being held up by conflicting traffic). Originally these delay relationships were based on theoretical formulae, but currently an empirical basis is used.

Assignment is based on an iterative multipath procedure which deals in time periods from six minutes to 24 hours. The technique assigns time-slice O-D patterns to the links in the network, such that arrival rates and updated delays can be derived. While queueing conditions are not modelled explicitly, the higher delays associated with oversaturation are considered in the assignment.

3.3/ Summary of Model Characteristics

In the previous section, each of the models has been summarized in a descriptive sense in order to provide an understanding of how it works.

In this section, their outstanding characteristics are summarized in tabular form. Table 3.1 will provide a basis for determining which models show promise in terms of the criteria outlined in Chapter 2.

Table 3.1 indicates how each of the models treats the following:

- Assignment
- Freeway Flow
- Traffic Signals

It also traces their roots, and summarizes model type and purpose to aid in the selection of models for more detailed consideration. To assist in the inclusion/elimination process, any standout characteristics are noted in Table 3.1 under the "critique" and "desirable characteristics" categories.

CORQ, CORCON, CONTRAM, and SATURN were each treated separately in Table 3.1.

Table 3.1/ Comparison of Models

Model	Assignment		Traffic Flows		Roots	Model Type	Major Purpose	Critique	Desirable Features
	Technique	Other	Freeway	Signals					
FREFLO	—		Conservation equation dynamic speed-density (fluid flow)	—	Mack	Deterministic Macroscopic	Freeway (1 direction)		
FRECON	Diversion due to ramp metering		Modified from FREFLO	Simple travel time	FREFLO	Macroscopic	Freeway (1 direction)	Diversion not same as assignment	Adaptive discretization of step size
INTRAS (FOMIS)	—		Veh-specific time-stepping simulation	—	NETSIM	Stochastic microscopic	Study freeway incidents	No O-Ds	
TRAFFICQ	—	Paths specified by user	—	Individual -vehicles -pedestrians	Original	Microscopic	Urban network	No O-Ds	Considers pedestrians
FREQ	Diversion of Ramp Queue	Considers only a subgroup for re-selection	H.C.M. (speed -volume)	Simple travel time	Original	Macroscopic	Freeway + evaluate: priority lanes priority entry	Diversion not same as assignment	Linear programming optimization
CORQ	Incremental/ iterative	Reassignment of queued vehicles	Step function travel time	Implicit in travel time calibration	Original	Macroscopic	Queueing in freeway corridor	-Not user-friendly -directional assignment	Auto. network performance plots
CORCON	Incremental/ iterative + traffic diversion		Step function travel time	Implicit in travel time calibration	CORQ	Macroscopic	Queuing in freeway corridor	Problems with implementation	Fuel consumption and emissions
SCOT	UTCS-1: turning movements DAFT: minimum path		DAFT platoon flow based on speed-density	UTCS-1 individual vehicles	DAFT UTCS-1	Microscopic and macroscopic	Test real-time control policies for corridor	Model component incompatibilities; model no longer supported	Composite network

continued **Table 3.1/ Comparison of Models**

Model	Assignment		Traffic Flows		Roots	Model Type	Major Purpose	Critique	Desirable Features
	Technique	Other	Freeway	Signals					
TRAFLO	"TRAFFIC" (Nguyen)	Planning oriented, non-queueing	FREFLO	I: NETSIM II: TRANSYT III: WEBSTER	FREFLO NETSIM TRANSYT	Microscopic and Macroscopic	All networks	-146000 stmts. -reassignment of of queues? -TRAFFIC-no queue -TRAFFIC-no queue considerations	Composite network
DYNEV	"TRAFFIC" (Nguyen)	Planning oriented non-queueing	Flow histogram (NETFLO II)	Flow histogram (NETFLO II)	TRAFLO	Mesoscopic	Emergency evacuation	Non-queueing assignment	Detailed model of approach lane selection
CONTRAM	Incremental/ iterative (packets of about 10 vehicles)	Re-iterates over entire peak (traces path)	—	Delay = f(G/C, C, V/C) +queue delay platoons	Original	Mesoscopic	Evaluate urban signalized and unsignalized network	Modelling of freeways	-Good assignment -Recalculation of signal timing
SATURN	All or nothing		—	Cyclic profile $TT = A_o + B_o X^n + QT$	Original	Mesoscopic	Evaluate urban signalized and unsignalized network.	-No freeways; -very coarse assignment, of queues	Considers progression between signals
MICRO-ASSIGN-MENT			—	—	Tradit'l transport planning	Macroscopic		No queue reassignment	Simple structure

3.4/ Evaluation of Candidate Models

In general, no single model was found to be comprehensive in being able to model all the required factors at the desired level of detail. Some models are rather specialized and while they evaluate a given situation in considerable detail, often their approach cannot be generalized to all the situations one would like to consider. Conversely, other models are more comprehensive in scope, but account for less detail or overlook some of the important complications that are introduced when the scope is expanded.

In view of the needs of MTC to have a model of freeway corridors/networks which can perform assignment, deal with queueing, and accommodate traffic signals on parallel arterials, the following was concluded.

3.4.1/ Models Found Not Suitable for Further Analysis

Due to the importance of assignment and re-assignment in freeway corridors/networks, MACK, FREFLO, FRECON, INTRAS and TRAFFICQ were eliminated. In each case, the models appear to be very detailed in their treatment of traffic, but the lack of a true assignment procedure results in these models analyzing in excessive detail traffic flows which are not necesarily correct. While diversion procedures are present in some of these models, diversion is not assignment, rendering it inappropriate for corridor or network analysis. The weakness of these models at a large scale network level is not to detract from their usefulness in analysing localized traffic behaviour at a microscopic level. On the contrary, for such applications these models appear to be very suitable. Unfortunately, their increased sophistication prevents network level assignment considerations to be included, making them unsuitable for the applications being studied in Ontario.

MICRO-ASSIGNMENT contains a network assignment technique, but this technique does not consider queueing. The delays resulting from oversaturation during a given time slice can be accounted for, but the resulting queues are not considered in the subsequent time slice. Essentially, the assignment technique employed in this program is a very detailed version of traditional transport planning approaches, which is

difficult to modify to accomodate the needs of oversaturation or queueing.

While the SCOT model appears to satisfy most of the primary criteria, it is no longer supported. Furthermore, the same authors have subsequently developed TRAFLO and DYNEV, which are said to be improvements over SCOT. Consequently, SCOT was dropped from the short list of models.

3.4.2/ Models Retained for Further Study

The following models were retained for further detailed study:

- FREQ
- CORQ-CORCON
- TRAFLO
- DYNEV
- CONTRAM
- SATURN

FREQ was retained for further analysis as it is the closest thing to a standard in freeway models, and because it has a number of features not available in other models.

The CORQ-CORCON series is further evaluated due the fact that it appears to be the only model type which simultaneously considers queueing and re-assignment in a freeway/arterial corridor.

TRAFLO and DYNEV are retained due to their ability to model assignment in a composite network which might be coded at various levels of detail. The level of detail could permit very accurate modelling, while the "network-wide" approach is rather unique.

Finally, while CONTRAM and SATURN do not explicitly contain routines to accommodate freeways, their assignment and traffic modelling approaches appear to be compatible with the needs for such a modification.

3.4.3/ Summary of Preliminary Screening

The above preliminary screening has eliminated a number of models which are not suitable for the purposes of this study. However, this does not imply that they could not be effectively used for other applications which more closely match the model's capabilities.

The remaining candidate models are examined in more detail in the next section to establish which model should be adopted for modification, and which desirable features of the other models should be incorporated.

4/ DETAILED ANALYSIS OF SHORT LIST OF MODELS

The previous chapter narrowed the wide variety of different types of available models down to the most promising candidates. These candidates were selected as they appear to contain most of the required model components, or incorporate a model structure which is sufficiently flexible to be amenable to the required modifications. This preliminary analysis resulted in the following shortlist:

- FREQ
- CORQ-CORCON
- TRAFLO
- DYNEV
- CONTRAM
- SATURN

The first two models, FREQ and CORQ, are the most traditional types of freeway/freeway corridor models, as they consider primarily the freeway and any important or relevant parallel arterials. The next two models, TRAFLO and DYNEV, appear to have a more network-oriented structure, as they can consider assignment in a multi-directional network and appear to model at considerably more detail the different facility components. The final two models, CONTRAM and SATURN, are primarily traffic signal oriented assignment models which do not currently contain any freeway logic, but due to the importance of traffic signals in a freeway/arterial corridor appear to be of potential use.

The variety in models to be considered, as shown by the three basic pairs of above models, in general represent the three main directions of possible model development. The first group consists of proven freeway models to which more traffic signal oriented aspects must be added. The last group consists of promising traffic signal models to which freeway capabilities must be added, while the middle group represents efforts which appear to have already combined the assignment/freeway/traffic signal triad.

Each one of these models have already been briefly discussed in the previous section, but for the convenience of the reader, these features

are first reviewed and subsequently discussed in more detail. At the conclusion of this chapter, the final candidate models are recommended based on the arguments put forth in this discussion.

4.1/ FREQ

While there are a variety of versions of FREQ available, the following detailed review will concentrate on the core modelling structure that is present in virtually all of these versions. It is this core which most characterizes the model structure and which is the critical element in terms of imposing possible restrictions on further modifications or enhancements.

Essentially, FREQ is a freeway model which calculates the impact of a series of traffic flows which have been derived from a sequence of freeway ramp O-D patterns. Several oversimplified driver responses have been included to enhance the model (spatial, temporal and modal), but these as well as the various estimates of traffic impacts enhance much more the appearance of the model, rather than its fundamental structure. Consequently, the model often appears as a collection of disjointed pieces of model components which do not necessarily constitute as comprehensive an analysis tool as might at first glance be anticipated.

4.1.1/ Modelling of Ramp Control, Merging and On-Ramps

Ramps are controlled based on user-specified ramp capacities and modelled using a deterministic queueing model (diagram). Demands and capacities are constant over a time slice. The ramp queueing model does not consider physical length of queue (uses a "vertical queue"), but the distribution pattern of queued vehicles is preserved when vehicles are stored over more than one time slice. Queue dissipation in a final time slice is spread out over the entire slice but the delay estimates are corrected for any errors which result from this approximation. Queues on ramps are stored along with their corresponding destinations and are added to the next slice's demand.

Merging calculations are performed according to the 1965 H.C.M. (level of service versus density method) and excess demand is stored at the merge

point in a "vertical queue". Other than changing the demand, the merge queue is assumed to have no interaction with the mainline travel time and queueing analyses. In particular, the merge queue is assumed not to physically block mainline traffic when mainline queueing analysis is performed.

Weaving analysis is performed in accordance with the 1965 HCM, and the model only considers simple and two-part weaving. This weaving analysis uses the subsection demands in place of volumes (volumes released from on-ramp and merge point queues), where these weaving volumes are calculated from an O-D table for the time slice.

The method for dealing with off-ramp queueing analyzes overloads on ramp capacity rather than an overloaded diverge point. The former is felt to be more common, while the latter is not incorporated in the model. Again, the method assumes only a vertical queue (no spill back).

4.1.2/ Mainline Travel Time and Queueing Analysis

Speeds are calculated subsection-by-subsection and time slice-by-time slice as function of flow and presence or absence of queueing. The relationships are based on speed/(vol/cap) curves and the operating speed from the HCM is converted to an average speed. Both the non-queueing upper limb and queueing lower limb are considered.

A simple queue propagation formula, derived from Lighthill, is used to model queue growth and decay. The model does not modify ramp volumes due to blockage by the mainline queue and hence the model assumes that these vehicles enter or leave the freeway even though a mainline queue is present. The O-D pattern of vehicles stored in a mainline queue is not conserved, since the discharging vehicles are assigned the destination pattern of the time slice in which they leave rather than arrive in the queue.

Some approximations are used when queues collide. Routines which find the tail of the queue and compute the shock wave velocity of the tail as it moves up or downstream may either create or destroy vehicles if the queue disperses before or after the end of the time slice. In this

situation a message is printed informing the user of the change, but it is felt that these effects will tend to balance out, creating only minor distortions.

4.1.3/ Optimization

Some versions of FREQ come equipped with an integrated linear program to perform an "optimization" of on-ramp control using an upper bounding approach. There is no clear indication as to what objective function should be employed, but suggested possible formulations which one may attempt to maximize are:

1. flow on ramp multiplied by some relative cost value
2. vehicle miles
3. passenger-inputs
4. passenger-miles
5. flows (subject to capacity buffer)

considering typical constraints in the form of:

1. capacity of each section
2. capacity of each on-ramp
3. minimum rate at each on-ramp

4.1.4/ Spatial Response

Spatial response is defined in FREQ as a change in the traveler's route choice in response to the perceived changes in the freeway travel conditions. The route choice alternative, if available, is a flow-dependent parallel route which connects all origin-destination pairs. The alternate route is divided into subsections that correspond to the freeway subsection in length and configuration, and their capacity is held constant during simulation. Their traffic demand consists of flows (not O-D's).

Three types of sections are considered. On arterials with no signalized intersections, speed is considered to be independent of flow (free flow), but when V/C > .99, each additional vehicle is given an additional time

of one time slice. Arterial subsections with one signal are modelled using Davidson's equation (j = 0.1775 if progression is good, j = 0.9446 if poor), and if v/c > 1.0 then each vehicle is assigned a penalty of one time slice. For subsections with more than one signal Davidson's equation with the appropriate j is used.

In terms of spatial response, two categories of trips are considered: short-trips (those who have O-D in study area) and long-trips (only the trip origin is in the study area). The main difference between long and short diversion is that the former simply shifts them to the next on-ramp, while the latter shifts trips away from the freeway all-together.

Short trip diversions are made up of trips diverted from the freeway ramp to a parallel arterial. Such diversion reduces ramp delay and increases arterial time, and is therefore calculated using an iterative procedure. It is assumed that all drivers are considered at the same point in time. It is also assumed that actual travel times and delays are those after ramp metering, but that the next origin uses travel times and delays from before the diversion. Furthermore, diversion candidates are limited to vehicles in the queue at the end of the time-slice (apportioned to destination on a proportional basis). Also, diversion is only considered if additional ramp metering time is above some preset threshold.

Longer trip spatial response is calculated independently of short trip spatial response. It considers diversion to the next downstream ramp if drivers can save time and potential candidates are any on-ramp arrivals with destinations beyond the next on-ramp. It is assumed that all travelers consider diversion at the same point in time, and based on travel times and delays existing after the present optimization. Even after diversions, from ramp I to I+1, the number of vehicles and delays that are used for longer trip diversions are those that existed before the vehicles were diverted from I (said to slightly underestimate diversion, as downstream ramps have higher delays than those indicated by equilibrium assignment). Any diversion candidates are again limited to those in a queue at the end of a time slice.

4.1.5/ Modal Response

The model's modal response calculates the percentages of non-priority passengers that will shift to priority modes in response to the difference in priority and non-priority travel times. This analysis is based on elasticities which were determined empirically from 161 residents in San Francisco.

4.1.6/ Temporal Response

Temporal response is defined as a change in the time-of-day choice of a trip in response to the changed travel conditions on the facility (considered very dependent upon the scheduling needs of the individual and the other available options). The FREQ analysis does not recognize microscopic variability among users. The model is mainly based on travel time difference, but also travel time variance and threshold functions can be considered. The curves that are supplied for travel time variance are a function of trip length.

A traveller will consider shifting the time of the trip to some different time of the day if the difference in expected travel time at the respective times of the day is greater than a minimum perception threshold (which is a function of trip length). A significant difference is applied to a temporal shift function that translates time differences into percent shifts. Such percent shifts are shifted in multiples of a time slice. Three different types of travellers are considered:

1. choice is now or later (work to home)
2. choice is now or earlier (home to work)
3. choice is now, earlier or later

The total percent shift is the product of a "travel time difference" effect and a "number of slices" effect. The model also accounts for travel time effect on those people who have to be at their destination at a fixed time. In all cases, shifts are developed by beginning the response analysis at the most restricted time slice and proceeding to the most flexible time slice.

4.1.7/ Model Application to Estimate Traffic Management Impact

The analysis for purposes of traffic management impact studies includes calculations of fuel consumption, vehicle emissions and noise emissions. The model has been applied to northbound Eastshore Freeway Corridor (I-80, 10 miles long) (Roden et al, 1980). The section changes from 5-lanes to 4-lanes to 3-lanes.

4.1.8/ Model Critique

The strengths of the FREQ model series are its diversity in traffic impact measures, the comprehensive range of reponses it includes and the extensive testing that has been carried out for the present (and especially the previous) model versions. Its primary weaknesses are the lack of depth in the implementation of these measures and/or responses, the lack of consistency in integration of the model components, and the limited spatial scope of the network that the model is capable of handling.

The number of different traffic measures that FREQ calculates is extensive. Similarly, its consideration of spatial, temporal and modal responses appears to be impressive. Unfortunately, the lack of accuracy of the model in handling certain important modelling aspects makes any small "calculated" changes in pollution, noise, or modal shift inconsistent and insignificant with respect to the errors that are present in the fundamental modelling approach.

Specifically, FREQ provides only a very coarse treatment of the distribution of traffic between the freeway and any parallel alternatives. Parallel alternatives are only modelled very approximately, resulting in potentially very large errors in path selection, as these decisions are based on only small changes in relative travel times of competing alternatives. Furthermore, the fact that the model only considers path re-selection of people queued on freeway on-ramps, ignores any path re-selection from the freeway to the surface street when the freeway is busy but not congested, or any path reselection of users of arterial routes to the freeway if its travel performance improves significantly.

Other substantial approximations are made in a number of situations where queues are modelled without an account of spillback. This affects downstream volume estimates and the account of blocking upstream traffic. In addition, as the destination pattern of queued vehicles is not retained for use in subsequent time-slices, considerable errors in downstream traffic volume estimates may occur if O-D patterns change significantly between time slices.

A feature of FREQ which is not present in most other freeway models is a linear program. While conceptually this addition appears to be a good feature, due to the significant approximations in the model of the actual process, the linear program seems to optimize a problem whose representation of the actual field conditions may be too approximate to be useful.

Finally, it appears that FREQ consists of a collection of highly detailed extensions which have been added to a fundamentally weak base. Consequently, many of these extensions provide only marginal or insignificant overall contributions, as they are based on a modelling structure which inherently has a large error component already build in.

4.2/ CORQ

CORQ (Yagar, 1970 and 1975 a,b) is a dynamic assignment technique for assigning time-varying demands to a freeway corridor. CORCON (Allen and Easa, 1977a) is a modification and/or extension of CORQ, but due to the similarities between the two, this discussion will emphasize primarily CORQ. Any differences between the two are discussed in Section 4.2.9, but are generally unimportant for the purposes of the current comparison.

CORQ (CORridor Queueing) was developed to model the assignment of time-varying O-D traffic demands in a freeway corridor while allowing for the special effects caused by queueing. Essentially, the model considers a peak period as being divided into a set of time-slices, each with stationary O-D's which are sequentially assigned using a combined iterative/incremental technique. The model permits temporary oversaturation (i.e., short term demand greater than capacity) and accounts for this extra demand by serving it in a subsequent time period.

CORQ currently best handles a directional corridor due to the need to offset relative departure times in collecting the O-D data. Such offset corrections ensure proper vehicle interactions for vehicles leaving from different origins, but are usually much to complex to be applied in more than one direction.

4.2.1/ Flow Relationships

Central to the CORQ modelling technique is the representation of the entire flow-cost relationship as a step function, or as a series of consecutive piece-wise-constant components. During the assignment, each basic physical link is replaced by a number of hypothetical "parallel" sublinks, which directly correspond to each step in the flow relationship. When the capacity of a given sublink is exhausted, the sublink corresponding to the next step in the step function is introduced, which makes available a new increment of capacity but at a somewhat higher cost.

The entire link costs relationship can be considered in two components: a flow component which considers flow along a link (up to the queue tail), and a queueing component which occurs during the presence of a physical queue.

The flow component is a simple step-wise relationship, as outlined above, with user pre-specified step sizes. The queueing portion is modelled using a similar piece-wise linear "sub-link" with a queueing cost equal to q x S/CSQ (where CSQ = capacity to serve queue, q = queue size and S = time slice length). This value of CSQ can be a simple function of the conditions on strictly that link, or a more complex function of other downstream or apparently unrelated links which indirectly affect it.

4.2.2/ Assignment

The CORQ technique strives to calculate an equilibrium assignment for an entire peak period as a series of equilibria for each component time slice. For each time slice a fresh equilibrium is calculated based on

the specified O-D demands, plus any initial queueing that might be left over from the previous time slice.

The procedure is essentially a sequence of incremental assignments. Each increment step sets out to assign as large a portion of the time slice's O-D matrix as can be accommodated by the most critical sublink in the network. When this most critical sublink is found, a fraction of the O-D matrix equal to this limit is assigned to the network. Then, the capacity of this sublink is increased by invoking the capacity increment which corresponds to the next step of the flow relationship, and based on the updated capacity and travel time information, a new assignment increment is performed. This sequence of assignment increments is continued until the time slice's entire O-D demand has been assigned. As an incremental assignment may prematurely assign demands to ultimately incorrect links and as there is some difficulty in estimating capacities which depend upon flows, equilibrium is generally only achieved after a number of iterations of the above incremental assignment.

4.2.3/ Modelling Queue Growth and Dissipation

During the assignment, the queue size is monitored and compared to link storage capacity. When the nominal flow or storage capacity of a link is exceeded, queueing is considered to take place and no further vehicles are admitted to that link, resulting in blocking of the appropriate upstream node. Subsequent departures perceive an additional delay as outlined above, and may still select a path which includes the queued link if no lower cost parallel alternatives exist. Such queued arrivals are only assigned up to the point at which the queue exists, and are stored there until the next time slice. During the next time slice, any vehicles queued on a link at end of the previous time slice are re-assigned to the downstream node. Effectively, this means that any queue existing at a point in the network at the end of a time slice is assumed to be taken out instantaneously and fed back into the network as a new demand at the same point, at a constant rate, for the duration of the following time slice. Those vehicles are re-assigned to the remainder of their paths based on a recalculation of minimum paths.

Much like FREQ, CORQ approximates a queue which dissipates in a certain time slice as decreasing at a constant rate over the entire slice length, but off-setting corrections have been made to the accounting to allow for this. Currently there is no provision for queue spill back through major intersections, but there is provision for queues on freeways and ramps to extend back onto the freeway, ramp and surface street links.

4.2.4/ Representation of Physical Network

The CORQ network must be coded in a standard fashion in which roadways are presented by links joining nodes, and nodes are the places where demand and/or flow characteristics change. Each link can discharge all of the vehicles that it absorbs provided that these can be absorbed by the downstream link.

At-grade intersections are coded using separate links for each of the important movements. Turning movements at a given intersection are assumed to have a constant through-flow equivalent, which is assumed valid for small ranges of flows.

An intersection approach is modelled using a dummy link with zero length which is used to combine individual movements into a single equivalent "thru" volume. Consequently, capacity is defined in terms of equivalent units of thru-flow vehicles, but limits on either combined or individual movements are considered. The total cost is the sum of the movement cost and the approach cost.

4.2.5/ Merging and Weaving Sections

Two types of merging problems can constrain merge capacity, either backing in from a downstream link, or physical merging problems due to poor merging geometrics (less common today). It is therefore assumed that capacity is independent of inflow mix. Still there remain some problems estimating capacities as flows cannot be assigned until the capacities are known, whereas the merge capacities in turn depend upon competing demands. As a solution, dynamic estimates of capacity are used which are based on partial incremental assignments.

Separate links are used to model the separation of flows affected and unaffected by weaving, such that thru flows can select between multiple paths. The capacity of a weaving section and the effective number of lanes used by weaving vehicles can be estimated for a given set of weaving flows, while the capacity of the non-weaving section can be estimated from the effective number of lanes not used by weaving vehicles. No detailed weaving analysis is included in the model as adequate theory did not exist, but room is left in the program to incorporate it.

4.2.6/ Other Details

CORQ assumes that the driver knows the unit travel times of all the links during the current time slice, and assumes that these times will remain the same in the next time slice, if he does not reach its destination within one time slice. These travel times are assumed as the basis for path choice based on individual travel time minimization. In addition, the individual travel times that are used in choosing shortest paths have considered the fact that the queued vehicles are really the first to be served.

The model has provision for exogenously changing network characteristics at the beginning of each slice. Also, separate nodes for origins and destinations are used to avoid having people passing these nodes.

4.2.7/ Model Application

The model has been used to test and evaluate two metering modes: (Yagar, 1973) fixed rate and traffic-responsive. The original CORQ model was tested in the field in a case study of the Ottawa Queensway Corridor. CORCON has been applied by Allen and Easa (1977b) to study the Q.E.W. west of Toronto and by MTC to perform three internal studies.

4.2.8/ Model Critique

The main strengths of CORQ are its ability to incorporate the effect of queueing into the overall assignment methodology, and the use of time-slice O-D's. The former significantly increases the degree of

reality in the model when a significant number of vehicles must queue enroute, while the latter permits the model to emulate the dynamic growth and dissipation of queues due to short-term variations in traffic demand.

Its primary weakness is the fact that the model has not really gone through an evolutionary sequence of revisions as it was developed and applied to case studies. As a result, the actual code is ill-formatted, the output is not very user friendly, and some obvious simple refinements to the technique are lacking. For example, link flow-travel relationships and intersection delay versus demand relationships are static within the model. Rather than automatically deriving these relationships from basic user inputs or from intermediate results, these functions must be hand-coded by the user. Similarly, CORQ'S current output format tends to provide row simulation results which require further hand processing, rather than concise summaries of the relevant flows, travel times and queues.

In summary, while CORQ has a sound fundamental core model structure, the actual implementation of the model lacks in user friendliness. In addition, some specific model routines need to be updated to reflect and include a number of recent developments and trends in modelling traffic networks.

4.2.9/ Evaluation of CORCON Additions and Modifications

As CORCON uses the same core logic and programming code as CORQ, it suffers many of the same problems. Some of the extensions have enhanced the model's user friendliness, but none of them have adequately solved the more technical problems of CORQ.

Significant improvements in the user friendliness of the model have been achieved by formatting the model outputs in clearer tabular formats, and by permitting the user to select the amount and level of detail of output data. Similarly, the pictorial output of the turning volumes at major intersections makes it easier to interpret some of the results. Also, the classification by facility type and use, of delays, travel time, queueing and fuel consumption data, automates much of the tedious hand

calculations that would be required to generate similar statistics from CORQ's output.

The introduction of turning prohibitions to cut down on the number of required links and nodes appears to be a mixed blessing. The actual reduction in number of links and nodes appears to be rather trivial, while the additional administration that is required to deal with this "saving" is rather excessive. Technically, the reduction in number of links makes the coding more difficult to follow, while it also unnecessarily generates the need to devise a separate minimum path algorithm. It appears that if this marginal "saving" were not pursued, the "new" minimum path algorithm would not be needed, the model logic and results would be clearer, and the later derivation of a technique to re-derive turning movements would be redundant.

The queue diversion formula appears to be a similar over-kill as it solves a rather small problem using additional complications, where a simpler and more accurate solution was obvious. If drivers value the time spent in queue at a higher rate than the actual queueing time that is measured, one can simply weigh the queueing time more heavily in the minimum path calculations. This approach would automatically generate any estimated diversion, while the CORCON diversion formula is rather arbitrary and runs into several unpredictable complications when used in an incremental/iterative assignment technique.

Finally, the calculation of fuel consumption is a good feature, as reductions in fuel consumption are often used by highway agencies as a decision basis. However, it should be noted that it is not an improvement in terms of the actual modelling technique, due to its trivial formulation format.

Due to similarities of CORQ and CORCON, further analysis will consider only an aggregate format of both models which includes the core of the original CORQ plus any significant improvements that were made during the development of CORCON. However, as not all the CORCON additions have been proven desirable, the original version of CORQ will be employed as a basis to which any CORCON features, as well as any other improvements, are to be added.

4.3/ TRAFLO

The TRAFLO model was developed under a U.S. Department of Transportation contract and is described by Lieberman and Andrews (1980). It was intended to be a model package which would analyze the assignment of traffic in an integrated network consisting of traffic signals and freeways.

The model consists of a traffic assignment procedure and a system of four simulation models which can be used independently or in combination with each other. The assignment submodel takes an O-D pattern and assigns this pattern to the network to obtain estimates of link traffic flows. These traffic flows are then passed to one or more of the simulation submodels, which estimate the impact of these volumes and consequently the expected traffic performance. These four simulation submodels model traffic conditions to alternative levels of detail and routines are available which handle the interfaces at the boundaries between subnetworks, which are modelled by different submodels.

4.3.1/ Traffic Assignment Submodel

The traffic assignment submodel assigns a specified trip table to the specified network which is compatible with the four simulation submodels.

The technique is based on the TRAFFIC model (Nguyen, 1974), and calculates link specific volumes that minimize an objective function representing Wardrop's (1952) first principle. The technique is an adaptation of the convex-simplex method which searches for a globally optimum assignment, where "optimum solution" is defined as being a unique solution which minimizes some cost function.

The TRAFFIC model requires that link travel time is a function of volume as described by the U.S. Bureau of Public Roads formulation:

$$Ti = To,i \; [1 + a \; (Vi/ Ci)^{b}]$$

where: Ti = Travel time on link i at volume Vi.
To,i = Travel time on link i under free flow conditions.

Vi = Traffic flow on link i.
Ci = Capacity of link i.
a,b = General or link specific coefficients.

It should be noted that both the Bureau of Public Roads travel time function and the TRAFFIC assignment technique were developed for planning purposes rather than for traffic operations purposes. Specifically, the author of TRAFFIC indicates that the technique "is concerned with the nonlinear mathematical model of the problem, where ... no explicit capacity constraint is imposed on individual links".

4.3.2/ Simulation Submodels

The four traffic operation submodels can simulate the following types of networks, either independently or in combination:

- freeways
- corridors that include a freeway/ramp/service-road complex
- urban and suburban arterials
- grid networks representing the CBD's of urban centres

The user may partition the analysis network into subnetworks if more than one simulation model is to be used concurrently, or model the entire network using a single model format. In the former case the user must also specify "interface nodes" at the juncture of subnetworks.

The following is a brief description of each of the four component simulation submodels:

- Urban Level I Model

  This model is the most detailed as each vehicle is treated as a separate identifiable entity and three vehicle type distinctions are permitted (automobiles, trucks, and buses).

  The simulation moves vehicles based on activation times and leaves them dormant between activation times. Details of the model are provided by Davilla and Lieberman (1980).

- Urban Level II Model

  Level II is supposed to be an extension and refinement of TRANSYT, as the traffic stream is represented in the form of movement-specific statistical histograms. The simulation uses five histograms: Entry, In, Service, Queue, Out. Details of this model can be found in Yedlin and Lieberman (1980).

- Urban Level III Model

  Level III models the network's major arterials: collectors, distributors, circulators, and connectors. These routes either connect the high density area to traffic generators or to other high density areas. The models are based on Webster and Cobbe (1966).

- Freeway Model

  This model is said to be an extension and refinement of the MACK model developed by Payne, Thompson and Isaken (1973) at the University of Southern California. In this case traffic is represented through a fluid flow analogy by aggregate measures, such as flow rate, density, and space mean speed.

4.3.3/ Model Critique

Modelling of traffic flows in integrated networks involves performing assignment and modelling all sub-networks and the various interactions between them. TRAFLO has combined all the basic component elements into one modelling package, but these components are not necessarily compatible. Consequently, most of the interactions which may result are not accounted for.

TRAFFIC is a very good assignment model for purposes of planning when behavior according to the BPR equation is valid. However, in terms of traffic operations, the inability of TRAFFIC to deal with queueing, non-steady-state traffic conditions and dynamic assignment are detrimental. In view of this, the author of TRAFFIC indicat d that the model should not be used for networks in which demand exceeds capacity, as the model assumes that link demands in excess of capacity will still be served. Consequently, downstream links are modelled as being loaded with larger than actual traffic demands, spill-back from this link onto

upstream links is ignored, and downstream demands are underestimated when this accumulated queue is served in subsequent time periods.

The first error causes the model to predict much worse performance for these downstream links during the current period as the evaluator "thinks" that the traffic volume on the link is much larger than it actually is. The second type of error ignores the impact that one link might have on drivers which do not use this link, but are held up in queue on an upstream link that was blocked. The final type of error causes the model to underestimate the downstream volume in a subsequent link, as the model already considers the traffic to have passed through in the previous slice. Even though these errors result in virtually as many underestimates as overestimates of delay, they do not cancel as they occur at different points in space and time.

The use of different modelling approaches for various parts of the network has the benefit of permitting the user to tailor the level of detail and accuracy to the specific needs of the various parts of the network. However, each one of these models has different operating procedures and assumptions, leaving the user with a measure of network performance which is expressed in differing terms. Not only does this make evaluation difficult, it also makes integrated optimization unfeasible. TRAFLO may handle large complex networks consisting of differing subnetwork representations, but at a price. It will run only on mainframe computers, and then only using an overlaid memory structure.

Finally, the current TRAFLO model structure does not contain a feedback loop from the detailed evaluation model to the coarse assignment model. Consequently, the TRAFLO assignment is strictly performed using a rather oversimplified travel time/traffic flow relationship. While a detailed evaluation of traffic flow conditions is performed later on, this improved information is not available to re-adjust the original assignment.

4.4/ DYNEV

DYNEV was designed to estimate evacuation travel times in Emergency Planning Zones (EPZ) as part of a larger software system developed for the Emergency Exercise Simulation Facility. The model is an adaptation and refinement of TRAFLO. As such it has been able to improve on TRAFLO, but has also adopted some of its fundamental problems.

The model consists of two main components: PREDYN and I-DYNEV. PREDYN is a routine for interactive input or input modification, while I-DYNEV is a software system consisting of three functional components: a traffic assignment model, a traffic simulation model, and a traffic capacity submodel. The assignment model is a modified version of TRAFFIC, while the traffic simulation model is a modification of TRAFLO's NETFLO II model. The traffic capacity submodel is used by both the assignment and simulation models and performs a more detailed analysis of intersection approach capacities.

4.4.1/ Assignment Model

The assignment model used in DYNEV is a modified version of Nguyen's TRAFFIC. In terms of DYNEV nomenclature it "identifies best travel times for people to move from specified origins within the EPZ to destinations just outside the EPZ boundary", but it essentially performs the standard routing based on individual path minimization.

KLD expanded TRAFFIC to incorporate TRAFLO CAPACITY (i.e., computes Ci consistent with assigned Vi volumes) using three components:

- through and left-turning vehicles
- through and right-turning vehicles
- lateral deployment of traffic on an approach

This procedure is iterated through to provide self-consistent estimates. Based on tests, the authors found the procedure rapid, accurate, and unconditionally convergent.

The authors indicate that the "Traffic Assignment Model" used in this project represents the latest state-of-the-art and provides accurate estimates of link volumes, stratified by turn movement at the downstream node. These turn volumes on each link are subsequently input into the Traffic Simulation Program."

4.4.2/ Traffic Simulation Model

The traffic simulation model I-DYNEV is an adaptation of TRAFLO Level II, with extensions in scope to accommodate all types of facilities. Essentially, traffic streams are described in terms of a set of five link-specific statistical flow histograms: ENTRY, INPUT, SERVICE, QUEUE, and OUT. These flow histograms are manipulated using a procedure based on the approach that is used in TRANSYT.

The procedure identifies the characteristics of each turn-movement-specific component of the traffic stream. In addition, it recognizes when one component of the traffic flow is encountering saturation conditions even if the others are not. Furthermore, I-DYNEV logic also provides properly for treating spillback conditions reflecting queues extending from one link into its upstream feeder links.

The traffic simulation model is intended to replicate the dynamic (time-varying) movements of the traffic stream on all roadway sections. In addition, some route flexibility is introduced by permitting vehicles to deviate from the originally assigned route, if that route is congested and a feasible alternative is not congested. The primary function of this model is to collect traffic statistics.

The traffic simulation model takes as input link volumes and turning movements from the assignment model and uses these to predict expected traffic performance. Data outputs are provided by link and by using two alternative grid systems:

polar grid - 22.5 degrees ang x 15 miles = 240 cells
cartesian grid - 20 miles x 20 miles = 400 cells

4.4.3/ Traffic Capacity Submodel

The traffic capacity submodel services both the assignment and simulation models. It computes service rates by turn movement as a function of turn movements of oncoming traffic, geometrics, etc. These link service rates will, generally, vary in time. The basic structure of the analysis is a lane allocation/critical movement type of analysis.

The capacity of an approach to an intersection is calculated by the I-DYNEV capacity model based on roadway geometrics, control device characteristics and motorist behavioral responses (mean discharge headways, etc.). For roadway sections congested capacity is taken as a fixed fraction of freeflow capacity (the analysis uses 85% of the freeflow capacity).

4.4.4/ PREDYN

The main role of PREDYN is to serve as a routine to handle interactive input or input modification. The routine guides the user through data input by means of a menu, performs diagnostic tests, and permits simplified modification of the original input data file.

The network configuration generally only represents links in the direction of the evacuating traffic. Traffic demands are indicated by the origin zone for traffic to be evacuated. The user must also provide evacuation rates and vehicle occupancy information.

At the end of input through PREDYN, I-DYNEV is called. In general, each execution of I-DYNEV has to be hand started, but modified original data can be employed.

These are the basic steps in the DYNEV procedure:

1. Input roadway network configuration, evacuation trip table, and existing network.

2. Execute traffic assignment
   (compute routing and turning movements)

3. Possibly modify controls and/or trip table if improvements appear possible (repeat steps 2 and 3).

4. Execute I-DYNEV Traffic Simulation Model based on traffic volumes and turning movements generated from assignment.

5. Possibly modify controls and/or trip table if improvements appear possible (repeat steps 2 to 5).

6a. If step 5 affects routing, modify input stream and repeat process.

6b. If output of simulation is compatible with original assignment, procedure is complete.

4.4.5/ Model Critique

There are many similarities between DYNEV and TRAFLO in terms of their authors, the model philosophy and many of the model routines. While some parts of DYNEV are improvements over TRAFLO, the adaptation of the same core structure appears to have left DYNEV with the same fundamental problems. Furthermore, in terms of the needs of MTC, DYNEV is not very suitable as its code is currently classified as being proprietary. Still, as a guide to aid in MTC's model development, the following should be said: the most significant improvement of the DYNEV model is the introduction of a capacity submodel which permits capacity estimates to be updated within the assignment procedure. This should improve the overall accuracy of the assignment as the results of the assignment and the evaluation will be more consistent. However, this modification does not correct for any of the queueing problems which were previously outlined for assignment procedure that is used in TRAFLO.

A second major improvement of DYNEV over TRAFLO appears to be its superior input management capabilities. Such improved input handling reduces the overall time required to apply the model, and indirectly often also reduces the risk of errors.

In contrast with TRAFLO which consists of four evaluation submodels, DYNEV performs the modelling of all links using only NETFLO II (a method which models traffic flows as a series of flow histograms). While there are some questions regarding the compatibility of the four evaluation submodels within TRAFLO, it is as difficult to determine how a statistical histogram can be used to replace the functions previously performed by NETFLO I (NETSIM) and FREFLO.

Further difficulties with DYNEV (and with TRAFLO) revolve around the fact that a peak period of say twelve 15-minute time-slices (three hours), must essentially be modelled as 12 independent runs, one for each separate time slice. Not only is this very inefficient in terms of the person who must use the model, but more important it appears to completely ignore any interaction between consecutive time slices.

4.5/ CONTRAM

CONTRAM (CONtinuous TRaffic Assignment Model) is a computer-based traffic assignment/evaluation model which has been primarily designed for analyzing signalized traffic networks. The following discussion is based primarily upon the descriptions of the initial model by Leonard, Tough and Baguley (1978) and Tough (1978), and the user guide to Version 4, as per Leonard and Gower (1982).

CONTRAM is designed to perform assignment within a network which contains primarily traffic signal controlled or priority intersections. Delays at each intersection are calculated using an average delay function, plus any queueing formulation if required. Traffic demands are assigned in vehicle packets, which are incrementally assigned and reassigned in subsequent iterations. Cycle times and green splits can be optimized internally, but coordination between adjacent intersections is not considered. While no explicit provisions are made for modelling freeways, most features of the structure of the assignment technique appear directly applicable.

4.5.1/ Network and Demand Representation

Three link types can be considered within CONTRAM: signal-controlled, give-way, and uncontrolled; and for each of these lengths, free-running times, saturation flows and permitted turning movements must be specified. CONTRAM can therefore model signal controlled intersections, 'give-way' junctions, roundabouts and bottlenecks at merges. For signalized links, lost times and stage sequencing must be specified, while actual signal settings can optionally be calculated internally within the model.

Demands are expressed to the model in terms of origin-destination flow rates for each time interval (usually about 15 minutes). Each such flow is assigned to the network in the form of packets of constant size (typically about 10 vehicles). During the interval, these packets depart from each origin at a uniform rate and travel as an indivisible unit along the same route. The model then stores for each packet its route, and updates flows and delays on the links it uses. It is assumed that the O-D flow rates are unaffected by network conditions.

In the model three classes of vehicles can be identified: cars, buses, and heavy goods vehicles. Selected traffic movements can be prohibited for any or all of specified vehicle classes and certain vehicles can be fixed to a given route. This additional option permits certain demands to be assigned to a fixed path along specified links, which is useful in representing bus traffic or the experience of test vehicles.

4.5.2/ Assignment Procedure

After all vehicle packets have been sorted in order of departure time, they are sequentially assigned to their respective estimated quickest route using a tree-building algorithm. After the assignment of each packet, travel time estimates are recalculated, and this updated information is used in the assignment of the next packet, until all packets have been assigned.

As this first iteration is unlikely to result in equilibrium, subsequent iterations are usually employed. In these subsequent iterations, the

original assignment is modified by re-routing certain vehicle packets. The effect of re-routing is accounted for by reducing the flows and travel times of the original links, and updating those links that are now used. Such iterations continue until equilibrium conditions are sufficiently approximated to within pre-specified limits.

It should be noted that in this equilibrium approach CONTRAM varies in an important way from most other models. Traditional models perform an assignment for a given time period considering all affected vehicles, iterate upon this time slice to achieve equilibrium, and then advance to the next time slice to perform the same. CONTRAM, in contrast, performs an assignment for all vehicle packets considering all affected time slices and then iterates through all vehicles a number of times, without explicitly considering a "current" time slice.

While the latest versions of the model have all eventually resulted in equilibrium flows, the iterative procedure does not always necessarily result in equilibrium. Furthermore, it has been found that the number of iterations required to find equilibrium, depends upon the flow demands, the packet sizes chosen and the number of links in the network. For many traffic management purposes, satisfactory convergence was achieved in five to 10 iterations.

Initial versions of the model used the previous iteration's optimized signal setting to calculate new travel times, resulting in new signal settings for each iteration. It was found that small changes in signal settings could result in significant changes in the distribution of traffic, causing significant problems in finding equilibrium conditions. Later versions therefore fixed timings between iterations, resulting in better convergence.

4.5.3/ Travel Times and Delays

In addition to the free running times on each link, the model also calculates, where appropriate, up to three types of delay: oversaturation, red indication and random delay.

The oversaturation delay is calculated from a simple queueing diagram in which the demand is expressed as an initial queue plus a linear arrival curve, while the departure curve is determined as the minimum of the capacity rate and the demand rate. Additional delays due to spill-over into the next time slice are also taken into account. The red and random delay for signalized links is calculated based on the uniform component of Webster and Cobbe's (1966) delay formula, plus a different random component which is believed to be more appropriate for transient queueing conditions. All signals are assumed to be operating on a fixed-time plan, and co-ordination of and progression between linked-signals is not modelled. The random delay on a give-way link is calculated using a traditional queueing formulation which is truncated at 95% of capacity. No delay, other than oversaturation delay, is experienced by packets on uncontrolled links.

Initial versions of the model assumed vertical queues and had no restrictions on the storage capacity of links. These approximations are supposed to be improved in later versions of the model.

No explicit facilities are provided within CONTRAM to model freeway sections, and freeway merges or weaving sections. It should be noted however, that currently there appears to be no major obstacle to incorporating these features into CONTRAM based on the assignment procedure that is currently used.

4.5.4/ Optimization

System optimization within CONTRAM is restricted to the optimization of traffic signal timings. Specifically, three types of signal settings can be considered in the model:

- fixed cycle/fixed split
- fixed cycle/optimized split
- optimized cycle/optimized split

In each case, the quality of the optimization is constrained by the quality of the objective function formulation (i.e., the approximations used in calculating delays through the use of queueing formulae).

It should be noted that the model considers each intersection in isolation and that any progression between coordinated adjacent traffic signals is neither optimized nor taken into account. The lack of optimization restricts the efficiency of the model's performance predictions, while the lack of accounting limits the model's accuracy.

4.5.6/ Computation and Data Requirements

The CONTRAM4 computer program is written in Fortran IV and can be obtained under licence from TRRL.

The input data required by CONTRAM are the physical characteristics of the network, the number of trips between each origin-destination pair and their variation with time, and information to run the program.

CONTRAM4 can model up to 200 links (maximum of 75 give-way links) and 50 signals. Maxima of 50 origins and 50 destinations are allowed. Alterations can be made to the program to increase the size of these parameters to cater to larger networks. The program takes about 30 minutes, on a CYBER 170-720 computer, to run five iterations on a network with 64 junctions (14 signal controlled).

4.5.7/ Model Critique

While CONTRAM is currently limited to traffic signal applications, rather than freeways, the assignment technique within the model makes its model structure superior to most current models. The three primary reasons for this are discussed below.

In contrast to traditional models, which generally consider only the last demand increment as being truly "incremental" users, CONTRAM permits each vehicle packet in turn to be a marginal user. As a result, each network user decides upon his path seeing a fully loaded network, rather than a network which has only been loaded to the extent of the previous increments.

A second feature of this assignment technique is the fact that all vehicles passing through a queued link are queued for a short time

(depending upon the current queue size), rather than having a quantity of vehicles equal to capacity not being queued at all, while all additional vehicles are queued a full time slice.

Finally, the assignment technique circumvents the approximation of most previous models which required all vehicles to reach their destination within one time slice unless caught in a queue. The CONTRAM approach permits vehicles to take more than one time slice, even if they are not queued at any point along their path.

CONTRAM's main shortcoming in terms of the objectives of this study is its lack of routines to model freeways and associated merging and weaving sections. While the addition of such routines is certainly not a trivial task, there appear to be no major obstacles within the current model stucture which would prevent such an enhancement.

A possible further concern of using CONTRAM is its extensive use of memory and computer time. While this restriction does not limit CONTRAM's application for small signalized networks, it might be an important factor when considering much larger freeway corridors or freeway networks.

4.5.8/ Applications

The model is designed to be used to examine the effects of alternative traffic management schemes such as junction improvements, road closures (i.e., for pedestrian malls), one-way street systems, signal strategies, staggered time demand for origin-destination movements and so on. Applications of CONTRAM are documented by Talbot and Murray-Clark (1982, 1983), Coombe, Annesley and Goodwin (1983), and Stephenson and Teply (1984).

Talbot and Murray-Clark (1983) describe the use of CONTRAM by the Greater London Council to study, evaluate and test the feasibility of five of the road schemes proposed for town centres in Inner and Outer London.

The application of CONTRAM in the Arabian Gulf state of Bahrain is described by Coombe, Annesley and Goodwin (1983). In this study traffic

conditions were evaluated for the two main urban areas of Manama and Muharraq. Two models were employed: a Strategic Transport Model, for medium and long range planning and a Traffic Management Model, for short term planning. The long term model was used as a guidance for deriving modifications to the CONTRAM area entry and exit point flows, which may arise from network changes both inside and outside the CONTRAM areas.

4.6/ SATURN

SATURN is an assignment technique which has been specifically designed to be applied in networks containing primarily traffic signals. While its main features are the consideration of coordination and progression between signals, the model is strictly an evaluator and not an optimizer. The model is considered because of its signal capabilities, even though it currently does not have any freeway (or motorway) capabilities.

SATURN is a traffic assignment model which is carried out as a two phase process consisting of a detailed simulation model of delays at intersections and an assignment phase which determines the routes taken. The simulation model determines junction delays resulting from given traffic pattern based on the assumptions that a traffic flow pattern is constant for time periods of about 30 minutes and that a cyclical behaviour exists for traffic flows at intersections with a common cycle time of typically 60 to 120 seconds. The first assumption restricts analysis to the average system behaviour in a given time period, while the second assumption permits concentration of the simulation effort on one cycle, where traffic is represented as semi-continuous flow profiles.

4.6.1/ Modelling of Traffic Flows

Turning movements at each junction are modelled using the following four cyclical flow profiles (much like TRANSYT):

1. IN: upstream inflow pattern
2. ARRIVE: platoon dispersed downstream arrival pattern
3. ACCEPT: pattern during which vehicles are allowed movement
4. OUT: pattern leaving the intersection

Final outflow patterns are derived through iterative simulation since the upstream OUT pattern becomes the downstream IN pattern and because the ACCEPT pattern is a function of opposing traffic flow. Using this approach, the model accounts, to various extents, for:

1. delays caused by opposing flows
2. delays due to vehicles on the same link
3. shape of arriving platoons
4. effect of phase structure and offsets at signals
5. individual lane capacities

In its present format, SATURN models traffic signals, Pelican crossings, priority junctions (including merges) and roundabouts, while work to include freeways has been planned.

4.6.2/ Assignment Model

The assignment model selects minimum time routes through the network for each O-D using an equilibrium technique (Dow and Van Vliet, 1979) which is based on a succession of all-or-nothing assignments. The authors claim the 'fastest-route-only' assumption to be more valid for the small networks, which they evaluate, as the potential routes open to each O-D pair are relatively distinct.

The simulation assumes that link travel time is independent of flow and that turning movement delay is a function of turning volume. The intersection simulation model is employed to find delays for: zero flow, current flow and capacity, with all other flows (i.e., opposing traffic) fixed. Given these three points, a power function is fitted to develop the entire delay relationship for unsaturated conditions, while a straight line section is added to represent increased delays for demands beyond capacity.

The complete model is based on an iterative loop between assignment and simulation, where the simulation determines flow-delay based on turning flows, which are used to determine route choice and, as a result, turning flows. Delay variations with turning movement volumes are derived from fitted function while the variations of delay with opposing volume are

established through the subsequent iterations. Usually reasonably stable convergence could be obtained after four to seven iterations. While conceptually the modelling consists of two programs, the user only interfaces with a single package which contains both the assignment and simulation routines.

4.6.3/ Queueing Model

SATURN considers two types of queueing: transient queues, which build up every cycle but dissipate during the green phase, and permanent queues, which build up when demand exceeds the capacity of the entire cycle. The former is handled using the previously discussed cyclic profile approach, while the latter is described below.

In the assignment model, demands exceeding capacity are considered to experience delays proportional to queue size and it is assumed that queues build up at a uniform rate. This queued and unserved demand is assumed not to reach any downstream links, as SATURN's traffic flow model requires that simulated traffic leaving each junction in the network is within its capacity. This is accounted for in the analysis by taking the assigned demand flow at downstream intersections and reducing them to actual or simulated flows using a queue reduction factor. Any vehicles queued at over-capacity junctions in one time period (slice) are subsequently passed, as essentially fixed flows, to the next time period. In its current format, SATURN considers only vertical queues with no spillback or "blocking back" onto upstream links. However, efforts to incorporate this in subsequent versions are indicated as being underway.

4.6.4/ Model Outputs

The output of the SATURN model contains all the standard measures of network performance, which can be displayed as graphical output. In addition, it is possible to analyse O-D trips making up particular turning movement or to analyse travel times for each O-D pair. Further features include interactive analysis capabilities and a close linkage to the ME2 procedure, which can calculate "most likely" trip matrices consistent with both prior information and observed traffic counts.

4.6.5/ Applications

The application of the SATURN model to actual problems has been documented by Hall, Van Vliet and Willumsen (1980) for the Borough of Harrogate, while Choraffa and Ferreira (1982, 1983) illustrated the use of SATURN in assessing the impact of traffic management measures in Liverpool.

In the Liverpool study, the simulation network consisted of 154 nodes and 444 one-way links, while the complete assignment network consisted of 818 nodes and 1382 one-way links. The final runs on a UNIVAC 1100 computer required 99 K and 70 K of storage for the simulation and assignment stages respectively. Corresponding CPU times were less than one minute and three minutes, respectively. A typical run-through of six simulation stages consisting of building the assignment network and five assignment stages took between 15 and 25 minutes of CPU time.

4.6.6/ Model Critique

The main strength of SATURN is its ability to perform assignment in a network consisting of traffic signals while giving due consideration to the specifics of the platooning structure of vehicle arrivals and the phasing of the signals. An additional feature of the model is its close linkage to a program for generating synthetic O-D's, which is important in view of the traditional difficulties of obtaining accurate and recent O-D demands efficiently.

The main weaknesses of SATURN are its lack of a queueing based assignment and its current lack of freeway modelling routines. While a number of features have been included to allow the assignment model to approximate a number of queueing impacts, it is not clear that a simple queue reduction factor accurately models all the relevant features. Specifically, there appear to be difficulties in terms of queue spillback, the re-assignment of queues in subsequent time-slices, and the use of an "equilibrium assignment technique" which employs a combination of all-or-nothing assignments in view of queueing. It would appear that queueing should be directly accounted for in the assignment, rather than

being "finessed" in afterwards. While these weaknesses do not appear important for the applications that are usually considered with SATURN, they appear to be critical in terms of the criteria specified for freeway/arterial corridors.

4.7/ Tabulation of Detailed Evaluation

The models on the short list are compared in Tables 4.1 through 4.4 on the basis of the critical criteria as described in Chapter 2.

First they are summarized by general purpose and original source in Table 4.1. They are then evaluated and compared in Table 4.2 based on how they cope with the following elements:

- Freeways
- Traffic Signals
- Queueing
- Assignment

Table 4.3 compares the accessibility of these models on the following bases:

- Computer requirements
- Availability and developer support
- Outputs
- Documentation
- Necessity and feasibility of modifications

Finally, Table 4.4 highlights the special strengths and weaknesses of the short-list of models.

While the weaknesses tended to drive the elimination process where models were found deficient in terms of the needs of MTC, any special strengths of each of the models were noted for potential incorporation into the ultimate model(s) selected for development and application by MTC.

Table 4.1/ Purposes and Sources of Models

Model	FREQ	CORQ (CORCON)	CONTRAM	SATURN	TRAFLO	DYNEV
Purpose	Directional Freeway	Directional Freeway/ Arterial Corridor	Network of Signalized and Unsignalized Intersections	Network of Signalized and Unsignalized Intersections	Composite Freeway/ Surface Network	Dynamic Evacuation
Sources of Components						
- Assignment	N/A	New	New	New	TRAFFIC	TRAFFIC
- Traffic Flows	New	New	New	New	NETFLO I-III and FREFLO	NETFLO II

Table 4.2/ Treatment of Freeways, Signals, Queueing and Assigment

Model		FREQ	CORQ	CONTRAM	SATURN	TRAFLO	DYNEV
Freeway:	Flow Rep.	Fluid	Fluid	—	—	Fluid	Flow Profile
	Travel time calculation	HCM 1965 (speed/volume)	Empirical Step-Function	—	—	Conserv. Eqn. Speed-Density	Speed-density
	Optimization	Lin. Prog. Ramp Meter	Demand Resp. Ramp Meter.	—	—	?	
	Merging	HCM 1965	Included	—	—		?
	Weaving	HCM 1965	Window Prov.	—	—		?
Traffic Signal:	Evaluation	Davidson	Empir. tt-curve	Webster For.	Cyclic Profile	Various	Flow Profile
	Assigment	Davidson	Empir. tt-curve	Webster For.	Fitted Curve	BPR	BPR
	Co-ordination	No	Empir. tt-curve	No	Yes	Sometimes	Yes
	Self-calculation	No	No	Yes	Yes	?	Probably
	Optimizing	No	No	Yes,no co-ord	No	No	No
Queueing:	Spillback	Not on ramps	Yes	No	No		Assigment: No Simulation: Yes
	Holdback	Yes	Yes	Yes	Yes(Q red fac)		Assigment: No Simulation: Sort of
	Spillover	15 min	15 min	Continuous	15 min		Assigment: By hand Simulation: Sort of
Assigment:	Method	Diversion	Incremental/ Iterative	Marginal (packets)	Combination of all-or-nothing	TRAFFIC	Modified TRAFFIC
	Freeway	—	Incr/Iterative	—	—	TRAFFIC	TRAFFIC
	Surface	Diversion of ramp queues	Incremental/ Iterative	Packets	Combination of all-or-nothing	TRAFFIC	TRAFFIC
	Re-assigment en-route	Queues each timeslice	Queues each timeslice	Vehicle packets each packet	Queues next timeslice	No	No (optional diversion)
	Re-assigment O-D pattern	Next slice's destinations	Original destinations	Original destinations	Not clear	—	—
	Spatial Propagation	Within slice (except in Q)	Within slice (except in Q)	Traced in time	Within slice (except in Q)	Within slice	Within slice

Table 4.3/ Accessibility of Models

Model		FREQ	CORQ (Corcon)	CONTRAM	SATURN	TRAFLO	DYNEV
Implement:	Mainframe	Yes	Yes	Yes	Yes	Yes	Yes
	Micro	No	Yes	No	No	No	No
Source Code Availability		Yes	Yes			No	No (proprietary)
Cost:	Fixed cost	Negligible	0	$ 612	$ 525	Negligible	
	Variable cost	Negligible	0	$ 2625	$ 2900	Negligible	
	Support	Yes	Yes	Yes	Yes	Yes	Yes
Outputs:	Flows, queues, travel times	Yes	Yes	Yes	Yes	Yes	Yes
Document:	User's manual	Yes	No	Yes	Yes	Yes	
	theory	Yes	Yes	Yes	Yes	?	
Modifications:							
	Unnecessary	No	No	No	No	No	No
	Feasible	Possible	Possible	Possible	Possible	Difficult	NO

Table 4.4 : Strengths and Weaknesses of Models

Model		FREQ	CORQ (Corcon)	CONTRAM	SATURN	TRAFLO	DYNEV
Comments:	Primary Weaknesses	No traffic signals No assignment	No explicit traffic signals	No freeways	No freeways	Different subnet. models TRAFFIC (non-queueing) 146,000 lines	Strictly NETFLO II TRAFFIC (non-queueing)
	Special Strengths	Priority lanes Lin. program optimization Priority entry	Modelling of Q spillback/ service	Sophisticated assignment technique	Co-ordinated signals Recalc. of signal timings	Model detail tailored	Vehicle distribution between lanes Kalman Filter cap. recalculation

4.8/ Selection of Models for Development and Application

The final selection of models was performed considering both the models' current capabilities and their potential to be enhanced. On this basis CONTRAM and CORQ were recommended for further development and subsequent application.

FREQ cannot be used for the purposes outlined in Chapter 2 because it is not a truly network-based model. While its diversion technique might be sufficient for an isolated freeway corridor, where there is only a single parallel alternative, diversion is not adequate when several alternatives are possible.

Due to the basic requirement that a recommended model should have a queueing-based assignment technique, TRAFLO and DYNEV must be eliminated. While the evaluation portion of each of these models has some queueing capabilities, the TRAFFIC assignment technique does not consider queue assignment and/or re-assignment, and cannot easily be modified to do so.

CONTRAM appears more promising than SATURN for the type of applications that are considered in Ontario. Although neither model has provision for freeways in its current form, the flexibility of CONTRAM's assignment/evaluation/queueing technique appears to make it much more suitable for the required modifications. In contrast, the model structure of SATURN appears to be too signal-oriented to permit the model to incorporate freeways without major fundamental changes to its assignment and/or queueing analysis.

In view of the sound queueing based assignment technique that is at the core of CONTRAM, we feel that the required enhancements are possible, and have been led to believe that TRRL is currently considering them. Although we have not been encouraged by its developers to attempt to enhance CONTRAM, we feel that it would be useful to obtain a copy of the program in order to test and further examine it, especially as there is presently no single model which currently can satisfy all the criteria outlined in Chapter 2.

CORQ has the potential to satisfy all of these criteria and has been demonstrated to model a corridor effectively. However, it requires a number of enhancements, as outlined in detail in the next section.

In summary, both CONTRAM and CORQ are recommended as they are found to be best suited for the required modifications and have assignment techniques which can effectively deal with the dynamic growth and decay of queues in a network setting. However, modifications are required for both models, as CONTRAM, which contains a detailed treatment of traffic signals, has no freeway capabilities, while CORQ, which emphasizes freeways, has a weaker traffic signal base.

4.9/ Suggested Enhancements

Based on discussions with MTC staff and the criteria outlined in Chapter 2, it appears that a number of enhancements should be added to CORQ in order to improve its user friendliness and useability. These are listed in two categories, "immediate" and "future". The former are in accordance with potential application within one year, specifically to the Burlington Skyway Corridor, while the latter would have a two to three year lead time, and suggest application to the Highway 401 Corridor, Ottawa Queensway Corridor, and possibly the freeway network west of Toronto, including the QEW, and Highways 401, 400 and 403.

The immediate enhancements, which are required in order to allow CORQ to satisfy the *** criteria of Chapter 2, are listed in Table 4.5. These enhancements concentrate primarily on automating a number of functions which must currently be performed by hand, refining the link delay relationships, and streamlining the model's output format.

A number of desirable features, which are not immediately necessary, but which would enhance the user friendliness of CORQ, as well as its ability to cope with the requirements of the bi-directional Highway 401 corridor, are listed in Table 4.6. It is estimated that this effort would take about two years to complete.

Table 4.5/ Immediate Enhancements to CORQ

i) Automating the link flow-travel time relationship based on the following inputs:

- link length
- free-flow speed
- link characteristics
  - freeway
  - arterial
  - effective number of lanes in each direction

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ii) Automating the adaptation of intersection delay versus demand relationship based on the following inputs:

- cycle length
- green time
- saturation flow

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iii) Incorporation of random and congested delay into a single continuous expression.

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iv) Presentation of summaries of the following link performance characteristics:

- flows
- queues
- travel times

Incorporation of a method for pre-loading the trips which are insensitive to the anticipated control strategies in order to:

- reduce requirements of interactive data collection involving the driving public
- reduce data pre-processing
- reduce computer simulation time
- allow the assignment technique to concentrate on the truly marginal drivers and therefore increase the quality of the simulation.

Table 4.6/ Future Enhancements to CORQ

i) Representation of all flows as integers rather than as decimal values.
ii) Development of a graphics package for a microcomputer.
iii) Iterative calculation of green times (and possibly offsets) using the flows predicted in previous iterations.
iv) Ensure that CORQ can handle bi-directional corridors (for application to Highway 401).
v) Ensure that spillback through signals is adequately represented.
vi) Incorporate weaving, as appropriate, after the new US HCM is finalized or a more appropriate technique is accepted.
vii) Provide documentation to allow other users to apply the enhanced version of CORQ.

5/ CONCLUSIONS AND RECOMMENDATIONS

5.1/ Conclusions

Of the models which were evaluated, CORQ and CONTRAM show the greatest promise for evaluation of management schemes for networks consisting of freeways and signalized arterials.

CONTRAM cannot handle freeways in its present form. However, it appears that it could be upgraded to incorporate freeways. Although its developers feel that this would be a major task, and do not have a time-table for its inclusion, it would be useful to test the present version of CONTRAM on a sample network.

CORQ has a structure which is compatible with the needs and criteria outlined in Chapter 2, satisfying some in its present version and allowing for the incorporation of others.

The terms of reference classified the needs as immediate and future, respectively. Therefore, it is felt that the deficiencies in CORQ should also be addressed in two corresponding stages, one immediate and the other when time, resources and the practical need justify them. The immediate and future needs are therefore listed separately in the following section.

5.2/ Recommendations

5.2.1/ CONTRAM

CONTRAM should be acquired and studied in detail. A co-ordinated study of the theory of CONTRAM, in parallel with test runs on a sample network should allow an accurate overall appraisal of the model. This should identify what enhancements the model needs and provide a good estimate of the feasibility of incorporating enhancements.

5.2.2/ CORQ

Prior to further applications of CORQ the following enhancements are recommended:

- automating the generation of link flow-travel time relationships
- automating intersection delay functions as simple continuous expressions
- automating link performance summaries
- incorporation of a method for pre-loading trips which are insensitive to potential control strategies

The following CORQ enhancements are also recommended in order to make CORQ more user-friendly (but are not necessary for immediate application):

- representation of flows as integers
- graphics package for microcomputers
- calculation of green times
- calculation of weaving effects
- more generalized documentation

In addition, prior to application of the model to the Highway 401 corridor, it must be ensured that CORQ satisfies all of the requirements of a bi-directional corridor and incorporated the effects of spillback through signalized intersections.

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